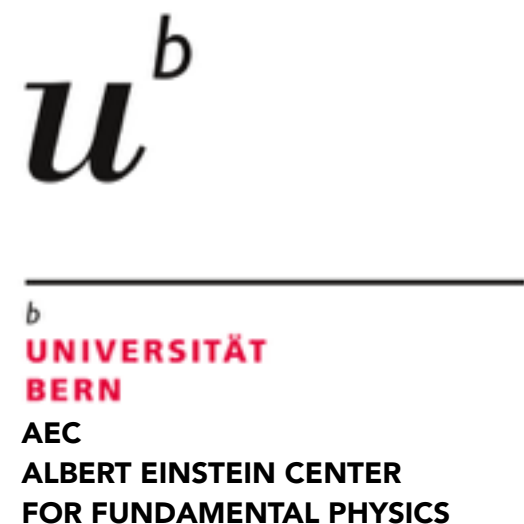# Recent Results from MicroBooNE

David Lorca
Albert Einstein Center — Laboratory for High Energy Physics— Universität Bern
on behalf of the MicroBooNE Collaboration

Flavour Physics Conference,
Quy Nhon, Vietnam
August 18th - 2017

UNIVERSITÄT
BERN
AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

μBooNE

- *Three Detector configuration*
- *Common Technology (LArTPC)*
- *Main neutrino beam: BNB*
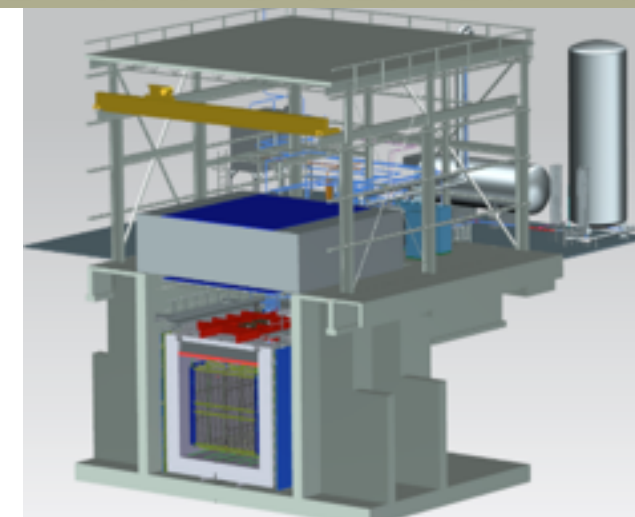- *MicroBooNE and ICARUS also receive NuMi beam*
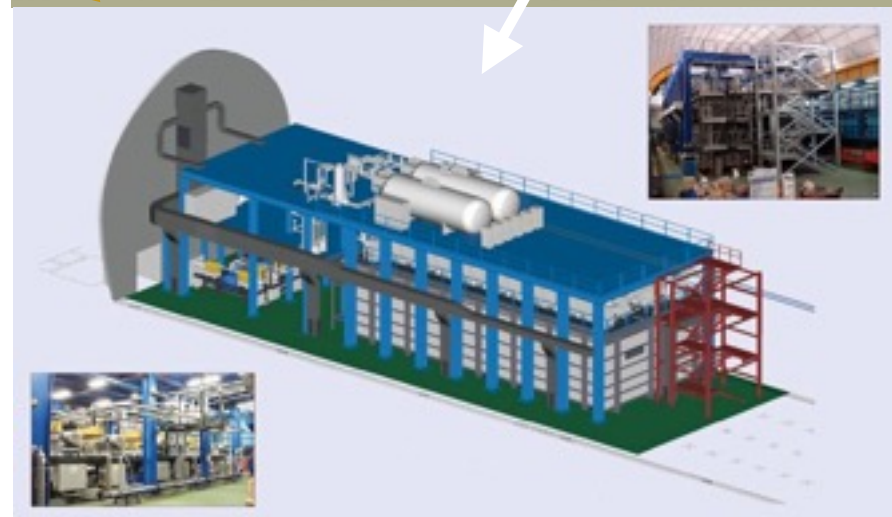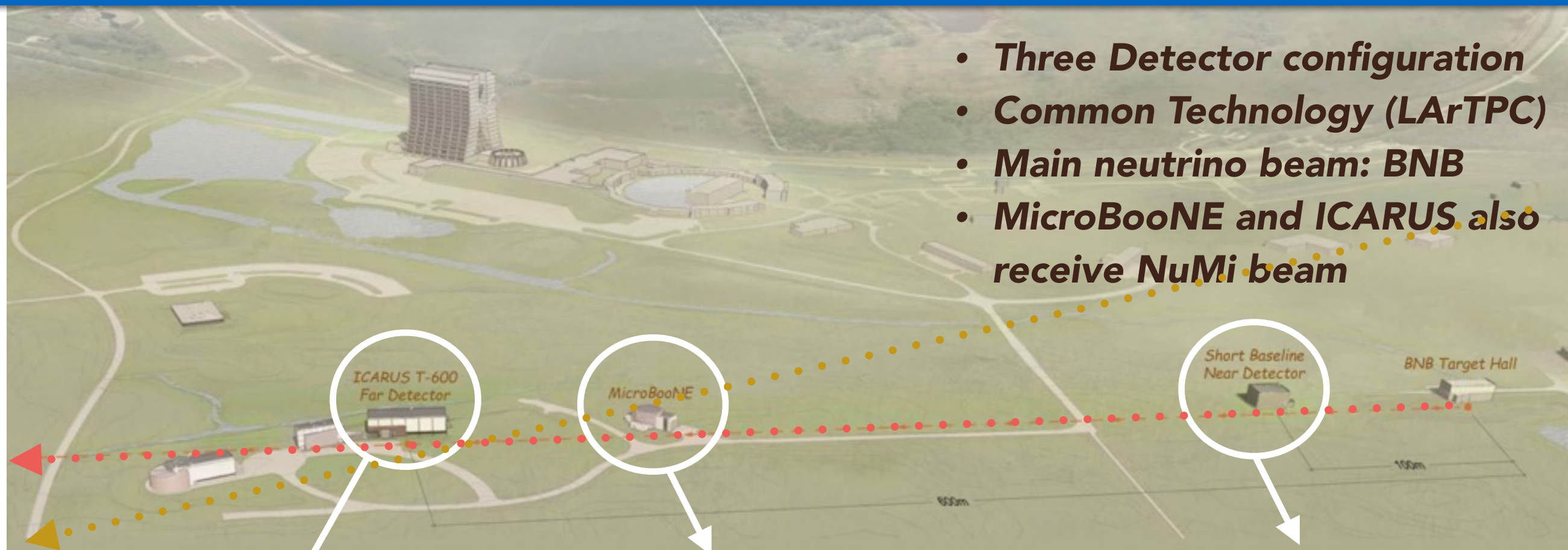
ICARUS-T600 *(2018)*

476 t LAr active mass
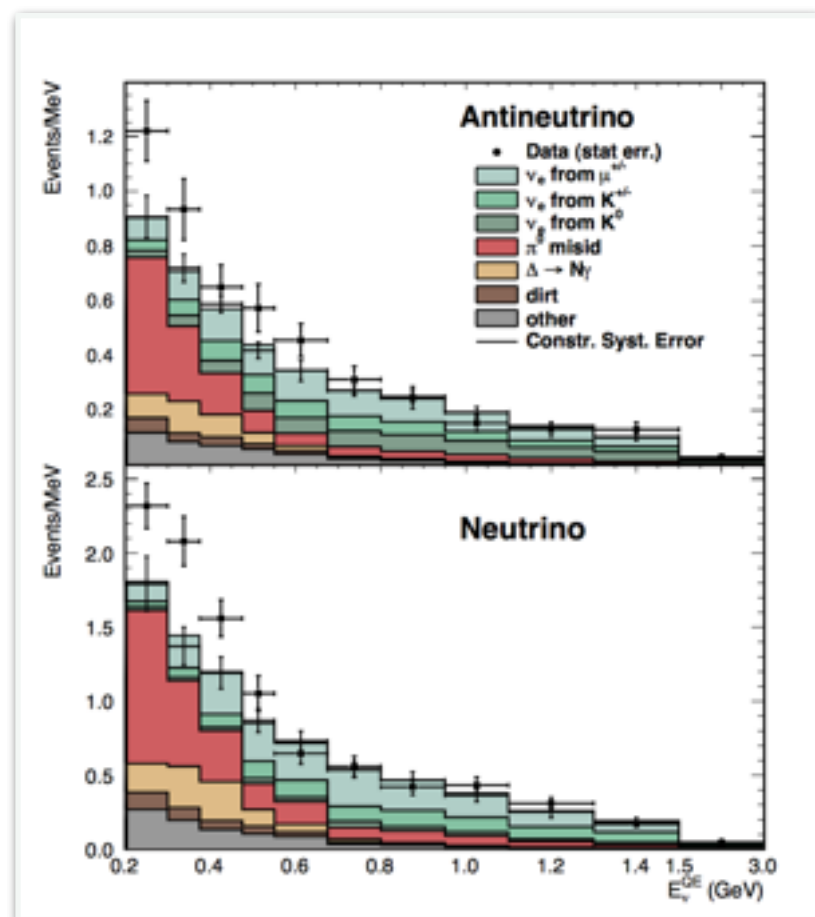*@600 m from BNB target*

MicroBooNE *(2015)*

89 t LAr active mass
@470 m from BNB target

SBND *(2019)*

112 t LAr active mass
@110 m from BNB target

Neutrino Oscillations

Neutrino Interactions

PDG 2015, Rev.

Cross-section measurement in ~1 GeV range

Neutrino mode:

Excess: 162.0 $\pm$ 47.8 (3.4σ)

Antineutrino mode:

Excess: 78.4$\pm$ 28.5 (2.8σ)

Combined:

Excess: 240.3$\pm$34.5$\pm$ 53.6

3.8σ significance

PRL 2013, 110, 161801

Supernova Neutrinos

Proton decay

Charge readout
3 wires planes:
- 2 induction planes
- 1 collection plane

2.3 m (Y)

10.4 m (Z)

2.6 m (X)
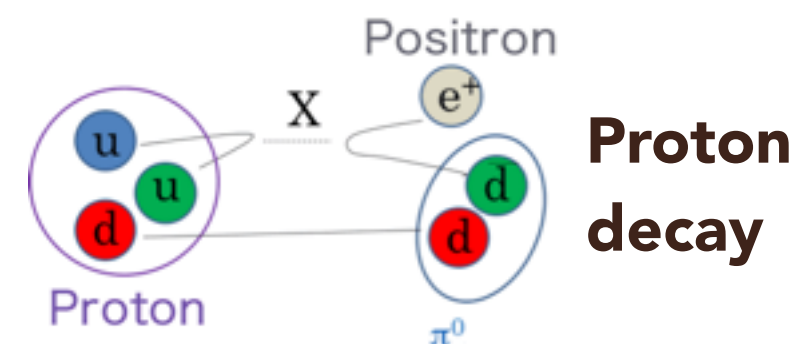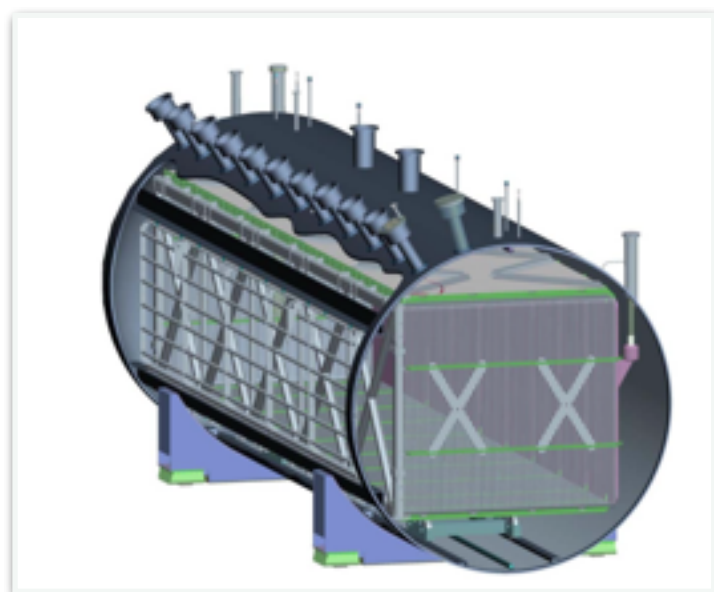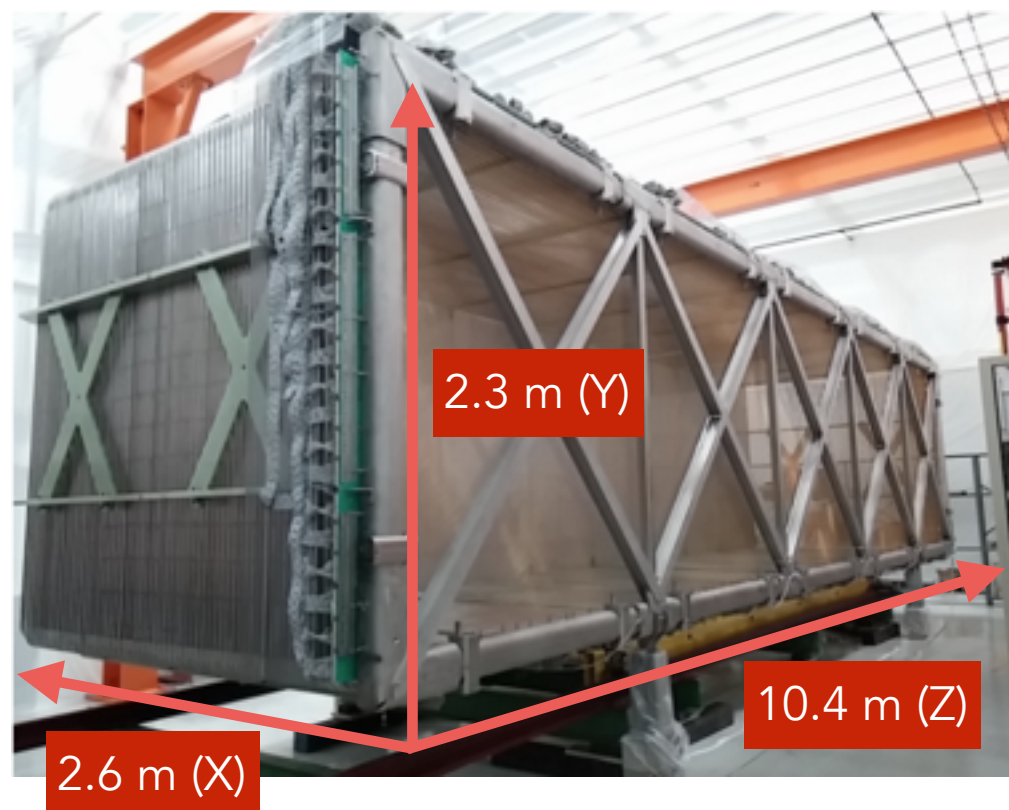
- Cold front-end electronics
- Laser Calibration system
- Understand & mitigate effects of surface operation
- Long drift (2.5 m)
- Large data volumes to store & reconstruct
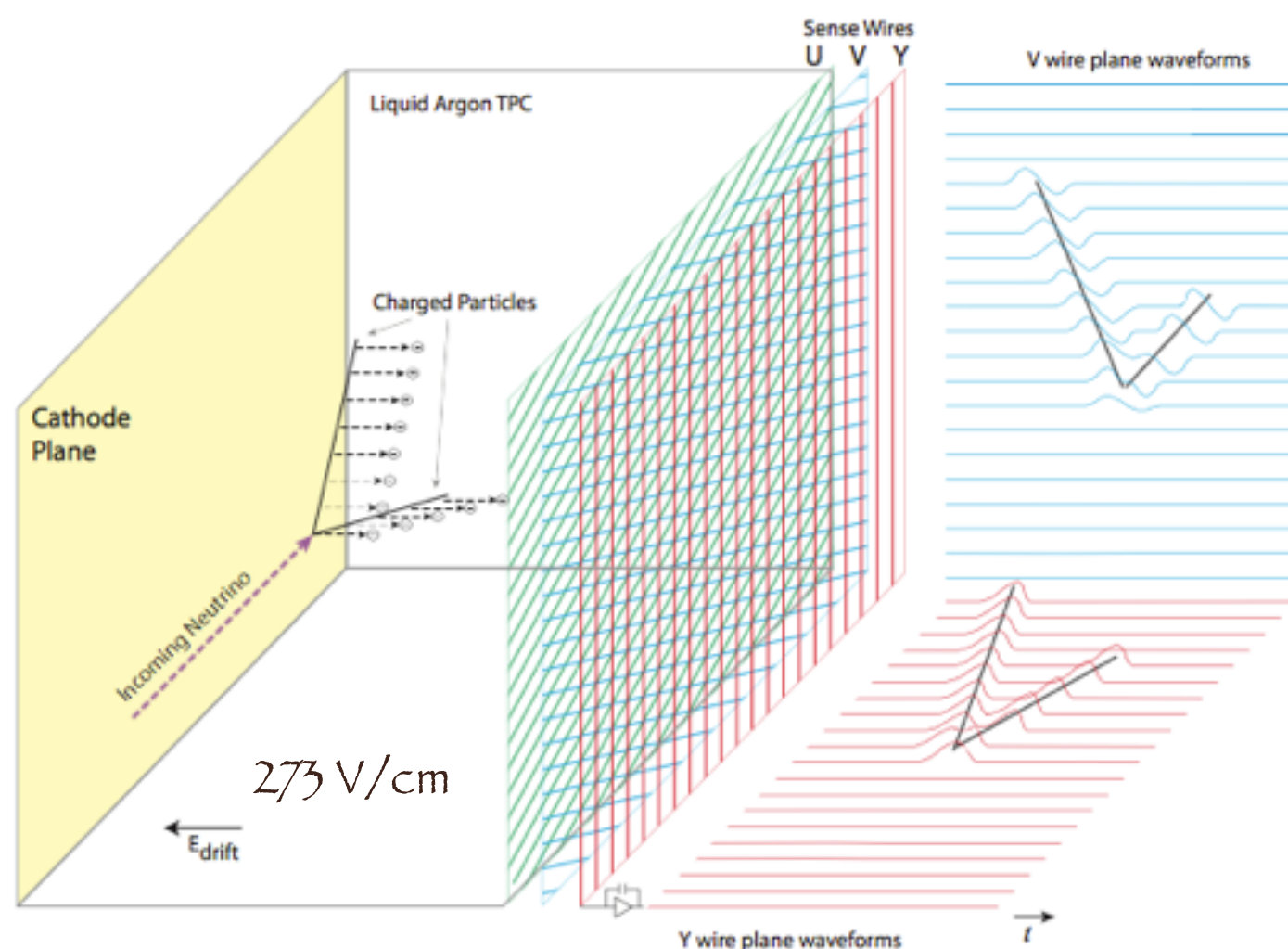- Dedicated supernova data stream

Optical readout:
32 PMTs with TPB WLS screens behind wires. Scintillation light provides trigger information.
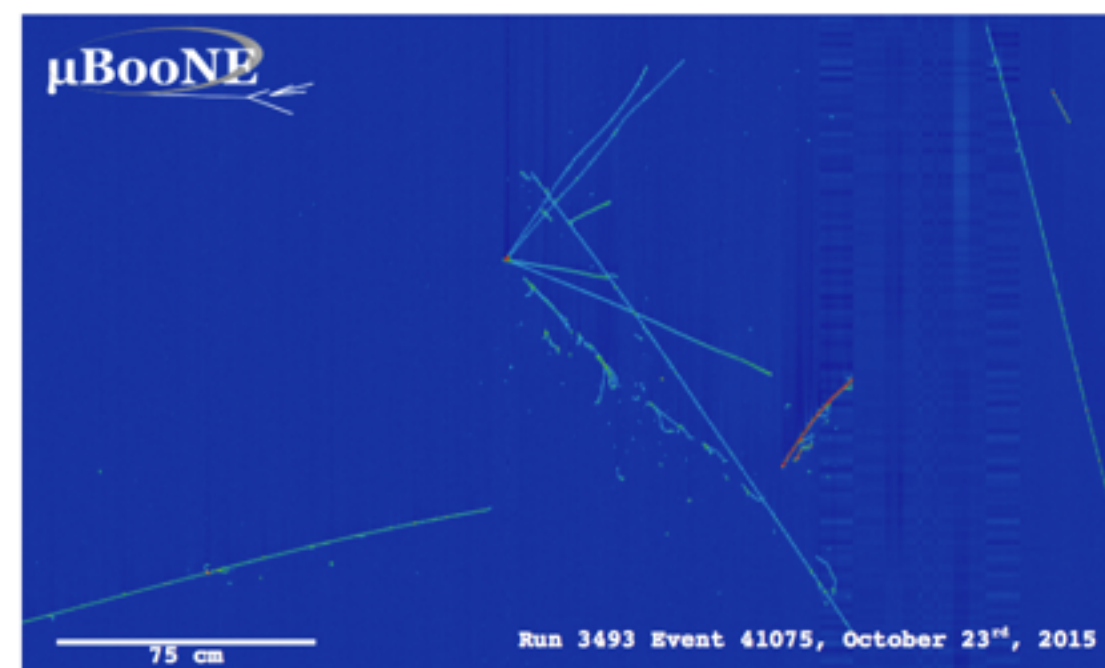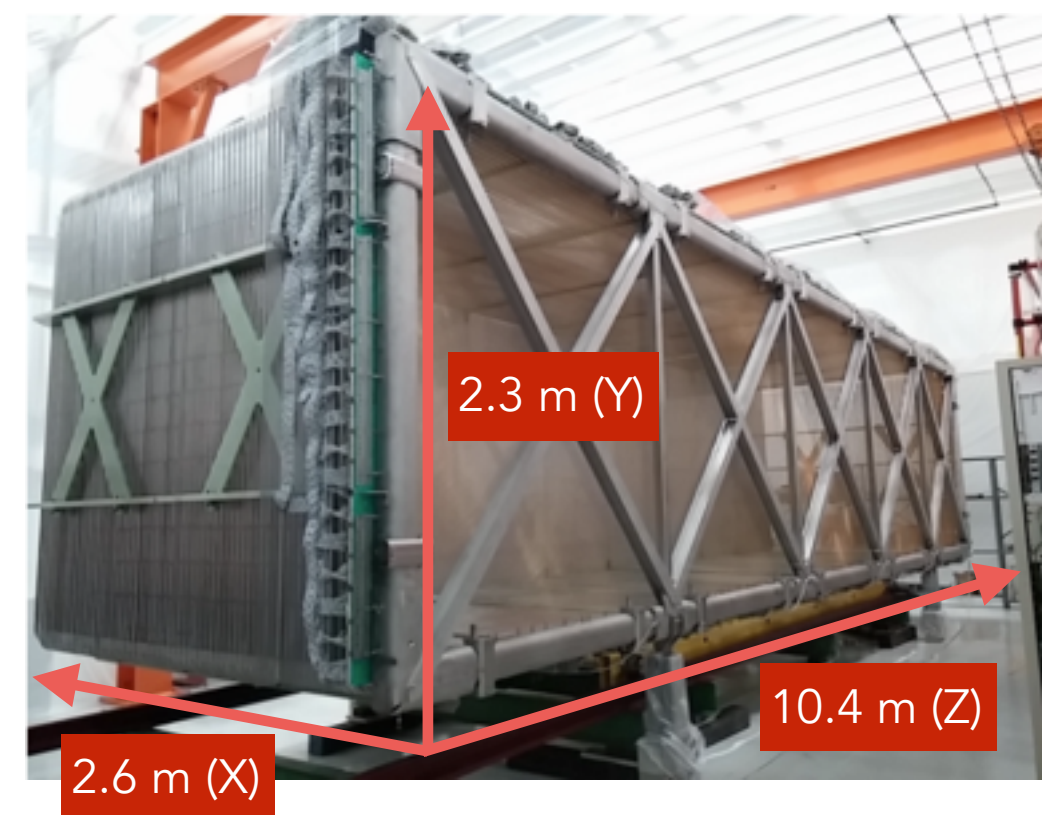
JINST 12, P02017 (2017)

And more …

Charge readout

3 wires planes (8256 wires / 3 mm pitch):
- 2 induction planes (U and V at +/- 60°)
- 1 collection plane (Y), vertically oriented

2.3 m (Y)

10.4 m (Z)

2.6 m (X)

Neutrino Detection in Liquid Argon

273 V/cm

TPC event display

Run 3493 Event 41075, October 23rd, 2015

75 cm

Installation and commissioning completed in October 2015

Neutrino interactions:

BNB:

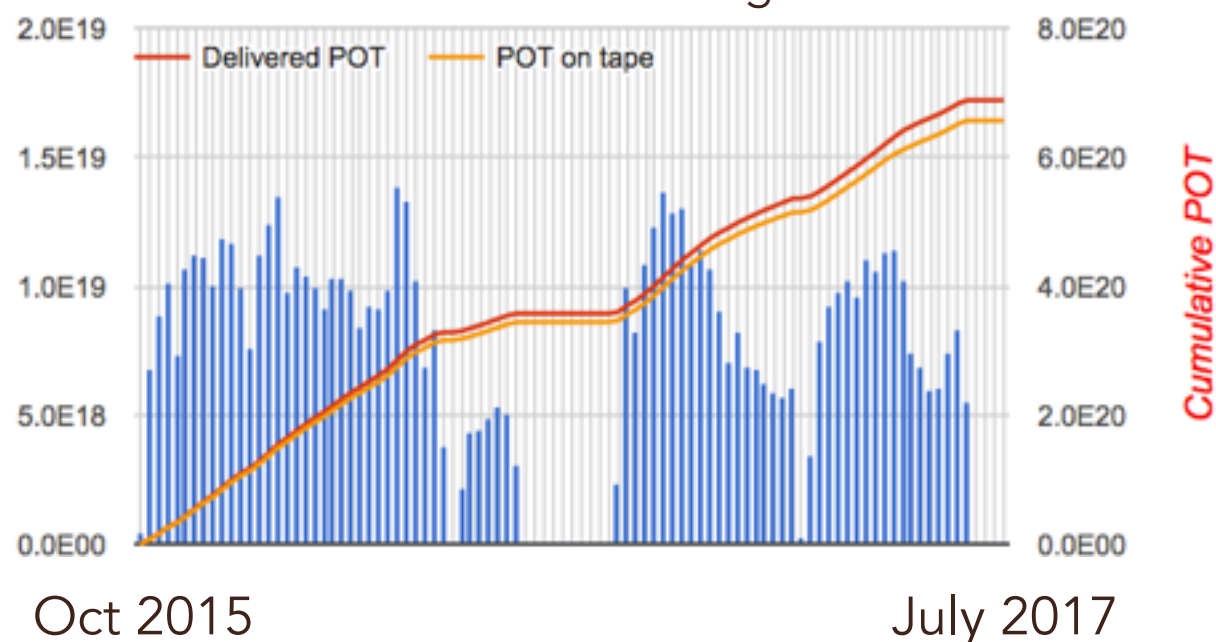~14000 ν_μ CC interactions

~55000 ν_μ NC interactions

NuMI:

~60000 ν_μ CC int. & ~12000 $\bar{\nu}_\mu$ CC int.

~25000 ν_μ NC int. & ~8000 $\bar{\nu}_\mu$ NC int.

BNB Protons On Target

Oct 2015   July 2017

NuMI Protons On Target

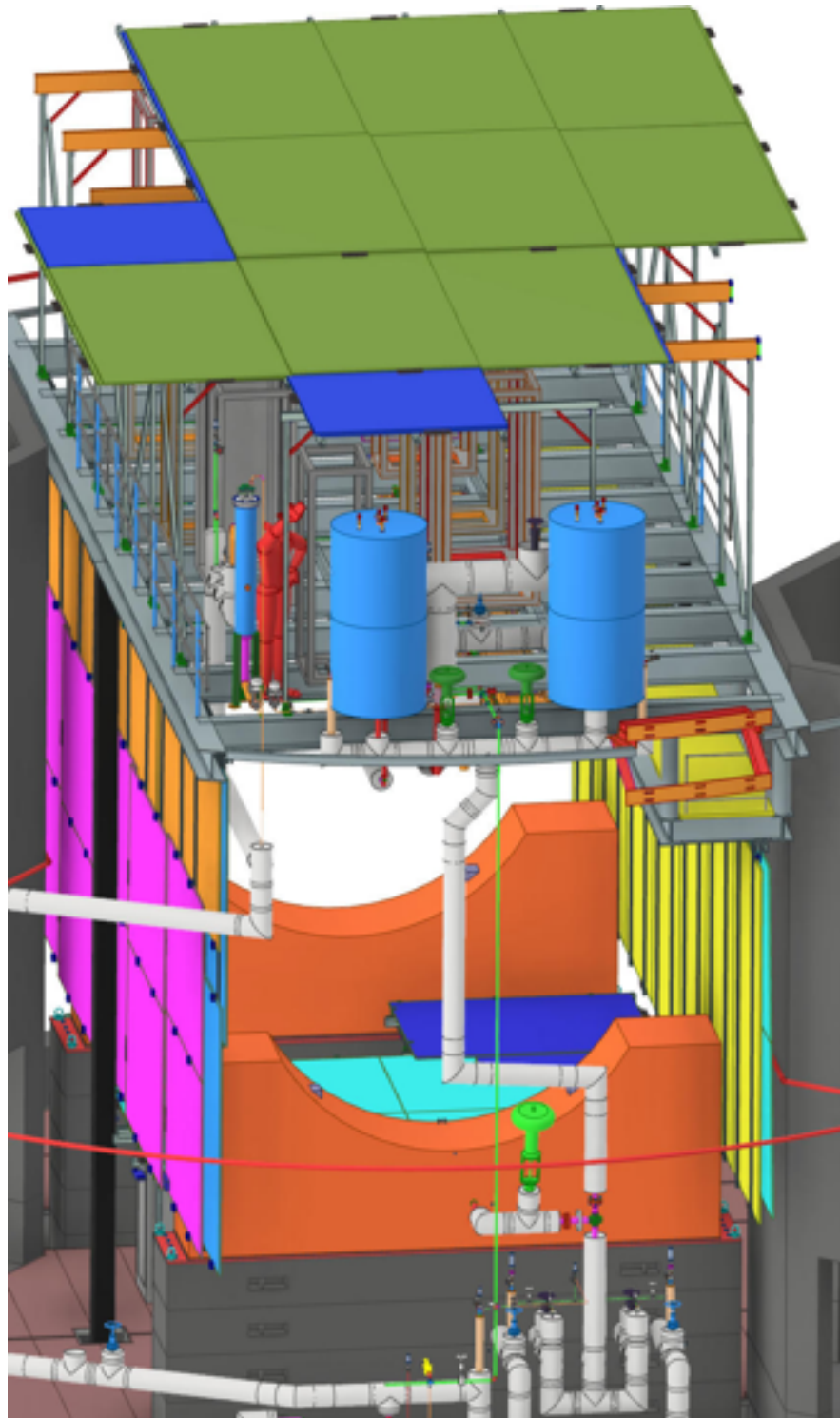Oct 2015   July 2017
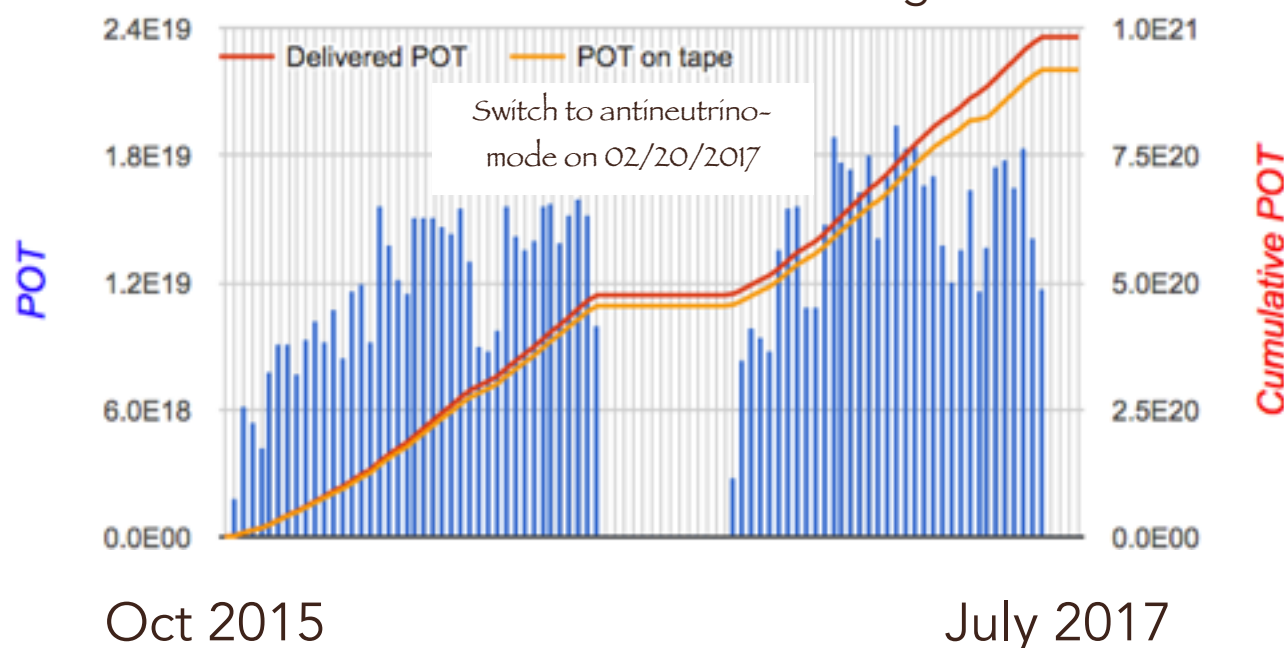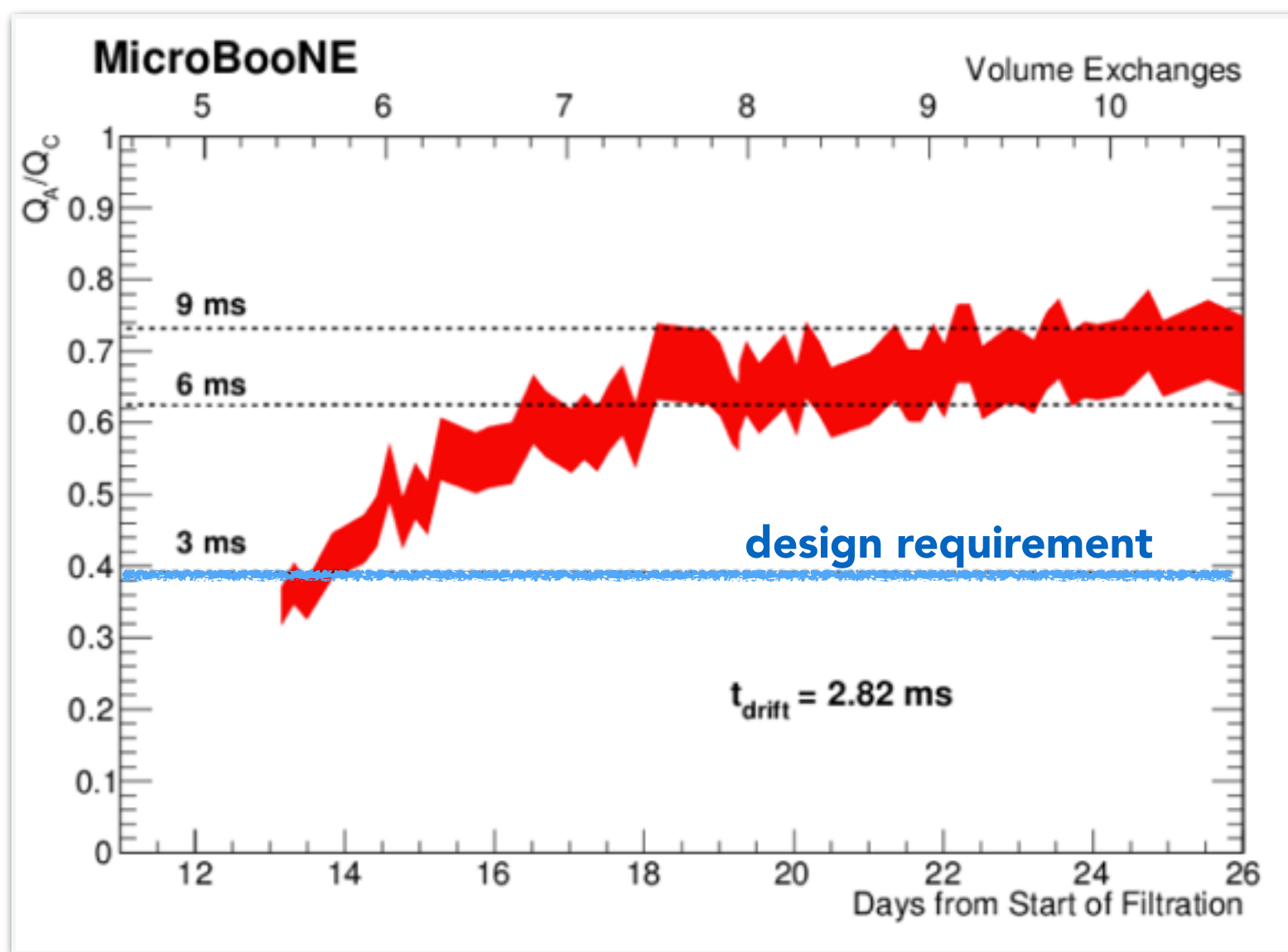
MicroBooNE Public Note 1003

- MicroBooNE drift distance (cathode to anode): **2.56 m**

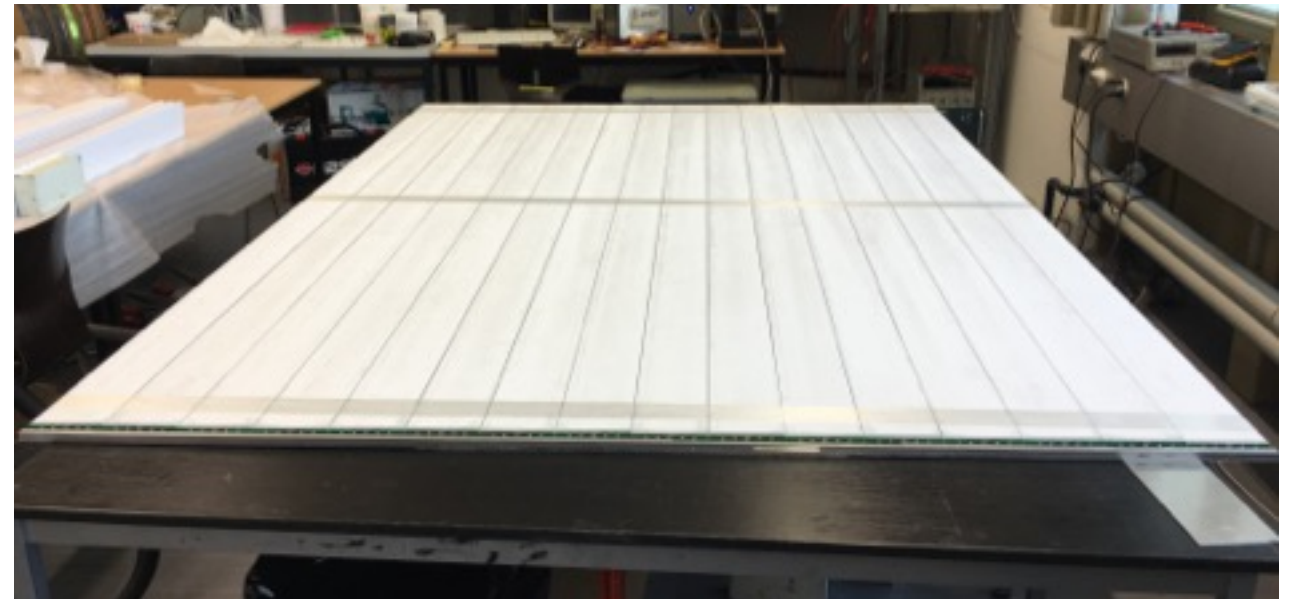- High-purity LAr is critical for the operation of a LArTPC

Using a combination of **gaseous purge** and **liquid argon purification** (no evacuation), design requirements were exceeded

Measure electron lifetime > 6 ms

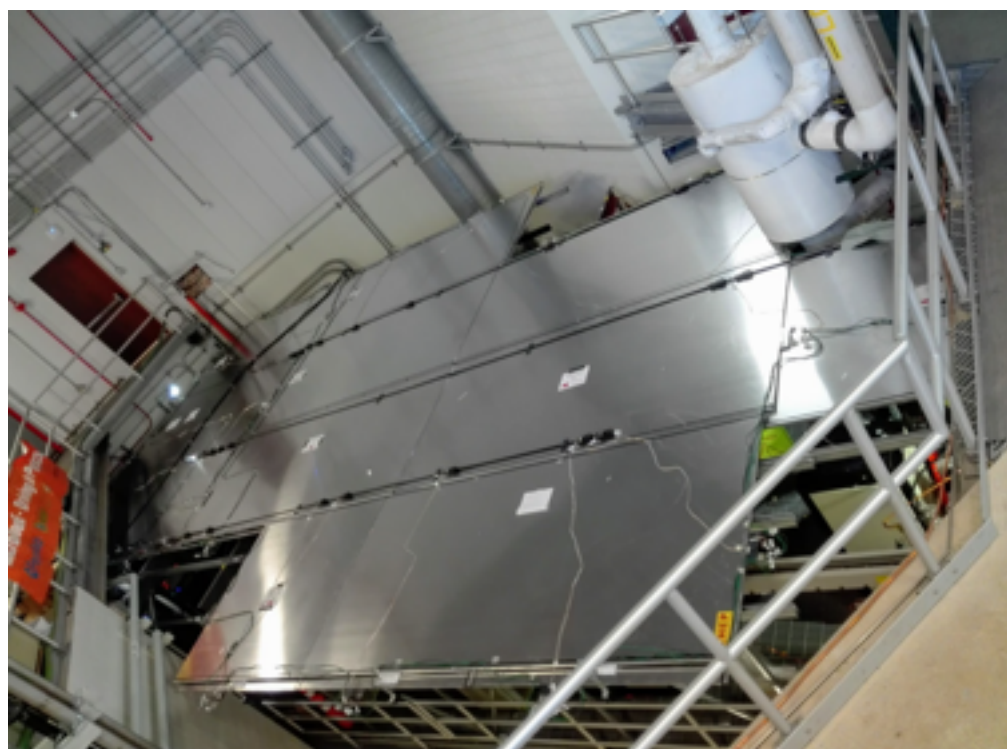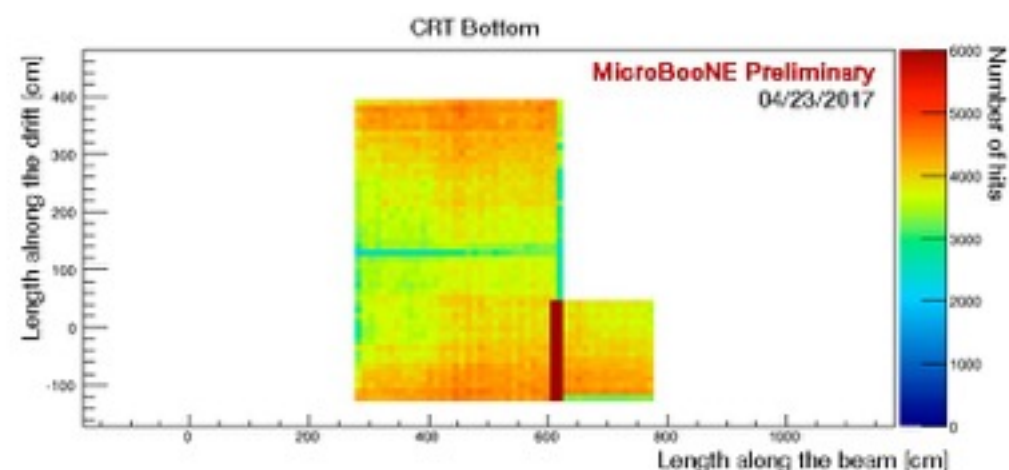The CRT will be used for cosmic removal and detector physics studies

- Plastic scintillator modules with SiPMs readout
- Custom electronics for digitisation and triggering (now licensed by CAEN)
- 73 modules in 4 planes surrounding the cryostat
- 85% coverage for through going muons

MDPI – Instruments 1010002

MicroBooNE Cosmic Ray Tagger scheme

CRT Bottom

CRT self triggered by two orthogonal modules

- 1D spatial resolution < 2cm
- Timing resolution ~3ns.

Installation and commissioning completed in March 2017
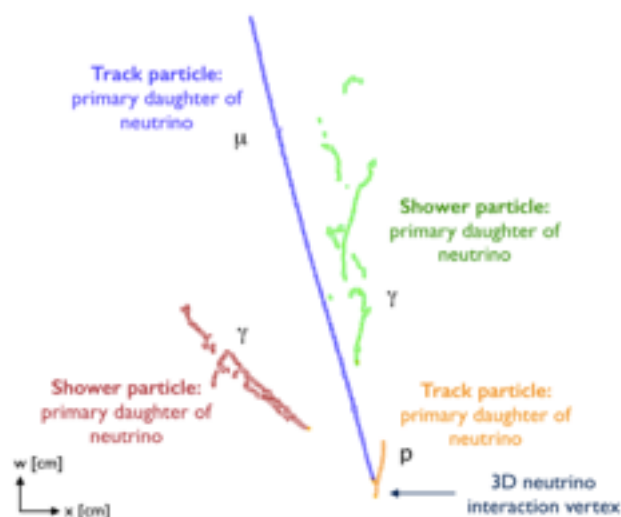
CRT Pipe Side
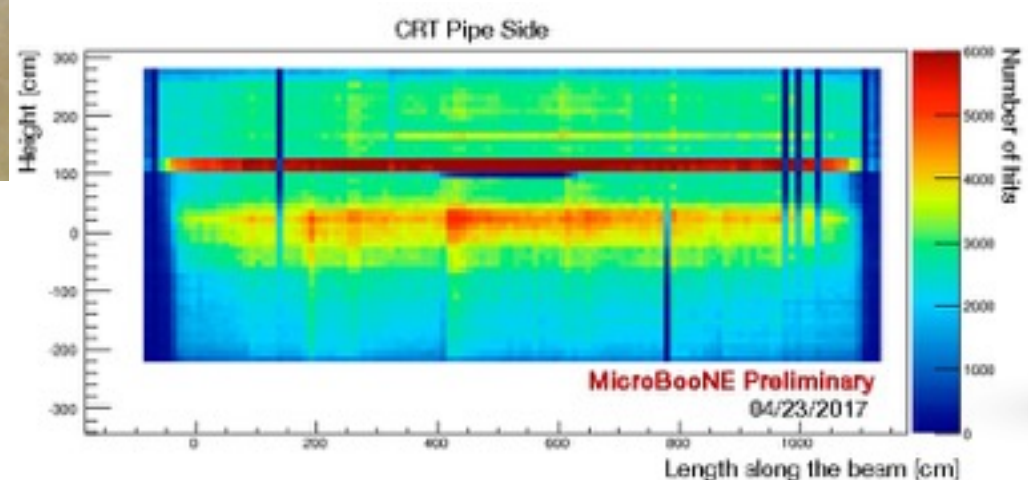
Currently implementing merge of CRT data into MicroBooNE data stream

CRT Feedthrough Side
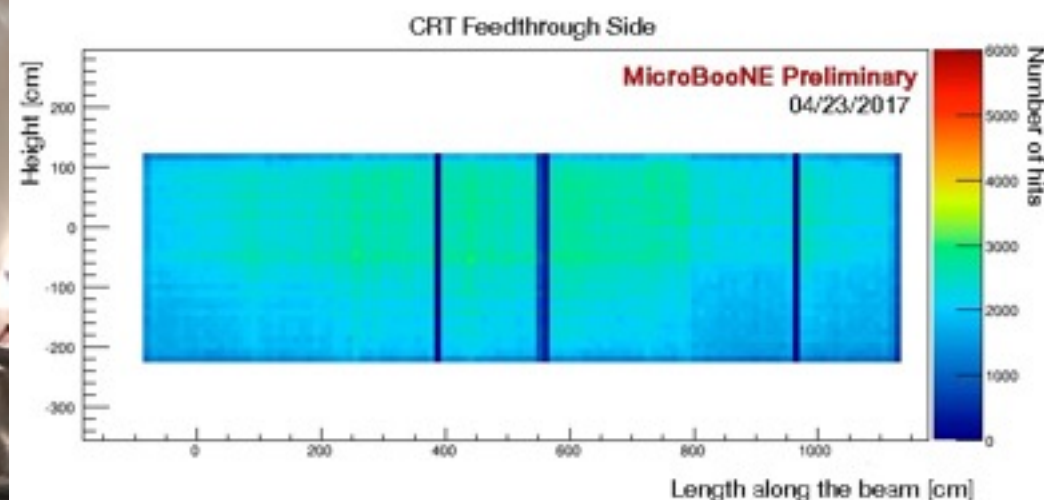
Already 7 publications and many public notes.
The collaboration is very active in using the data already gathered.

Publications by the MicroBooNE Collaboration:
◇ Public Notes page

◇ MicroBooNE collaboration, "The Pandora Multi–Algorithm Approach to Automated Pattern Recognition of Cosmic Ray Muon and Neutrino Events in the MicroBooNE Detector", arXiv:1708.03135, submitted to Eur. Phys. J. C.

◇ MicroBooNE collaboration, "Measurement of Cosmic Ray Reconstruction Efficiencies in the MicroBooNE LAr TPC Using a Small External Cosmic Ray Counter", arXiv:1707.09903, submitted to JINST

◇ MicroBooNE collaboration, "Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC", arXiv:1705.07341, JINST 12, P08003 (2017)

◇ MicroBooNE collaboration, "Michel Electron Reconstruction Using Cosmic Ray Data from the MicroBooNE LAr TPC", arXiv:1704.02927, submitted to JINST

◇ MicroBooNE collaboration, "Determination of Muon Momentum in the MicroBooNE LAr TPC Using an Improved Model of Multiple Coulomb Scattering", arXiv:1703.06187, submitted to JINST

◇ MicroBooNE collaboration, "Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber", arXiv:1611.05531, JINST 12, P03011 (2017)

◇ MicroBooNE collaboration, "Design and Construction of the MicroBooNE Detector", arXiv:1612.05824, JINST 12, P02017 (2017)
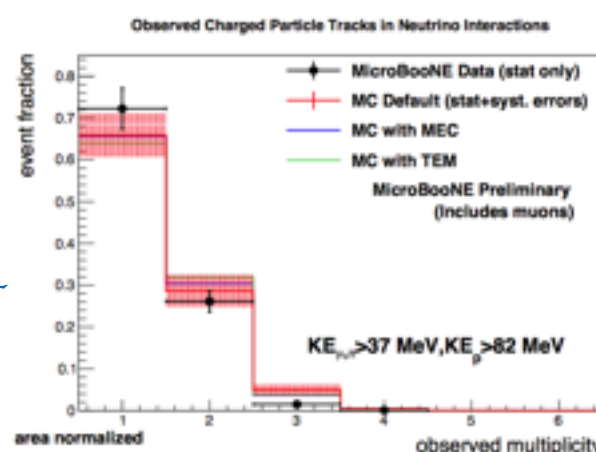
Measurement of Reconstructed Charged Particle Multiplicities of Neutrino Interactions in MicroBooNE
MicroBooNE Public Note 1024

Observed Charged Particle Tracks in Neutrino Interactions

- MicroBooNE Data (stat only)
- MC Default (stat+syst. errors)
- MC with MEC
- MC with TEM

MicroBooNE Preliminary (Includes muons)

$KE_{\mu}>37$ MeV, $KE_p>82$ MeV

MicroBooNE Publications page

Pandora pattern recognition
MicroBooNE Public Note 1015

Proton Track Identification in MicroBooNE Simulation for Neutral Current Elastic Events
MicroBooNE Public Note 1025

Run 5832 Event 2210. April 8th 2016

Today's talk:
- Noise characterisation
- Event reconstruction
- Low energy response
- Space charge effect

Example of Excess Noise
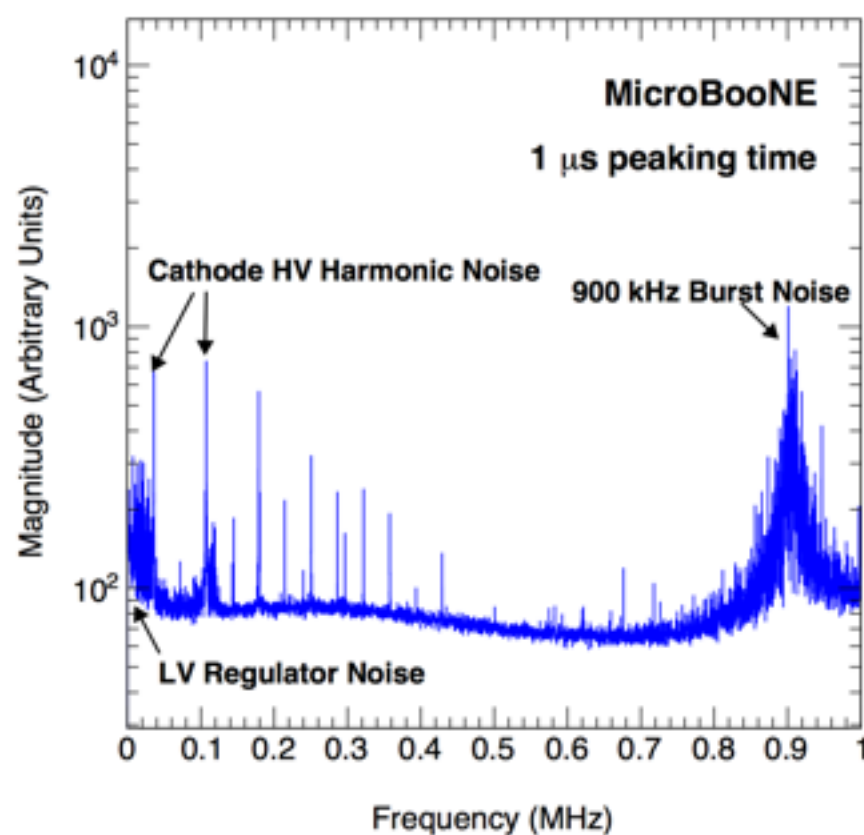
- Low-noise operation of readout electronics is critical for reconstruction purposes.

- Using first year data, several noise sources in the TPC were identified and mitigated.

- Hardware upgrades and noise filtering techniques improved the signal to noise ratio on all planes >16.

JINST 12 , P08003 (2017)
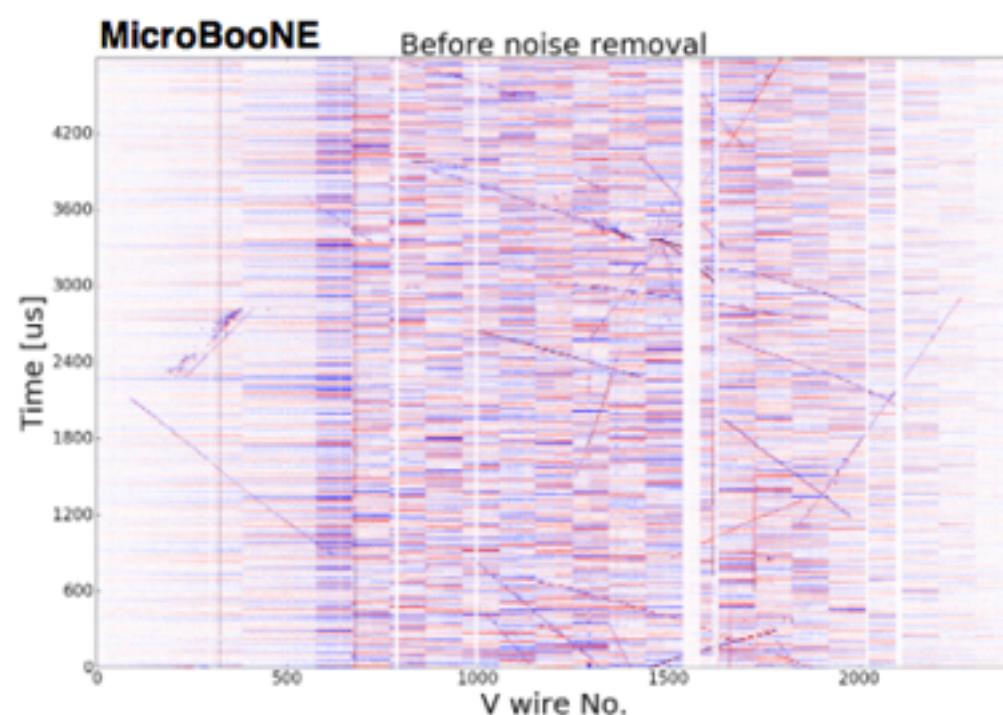
2D event display

(same event)
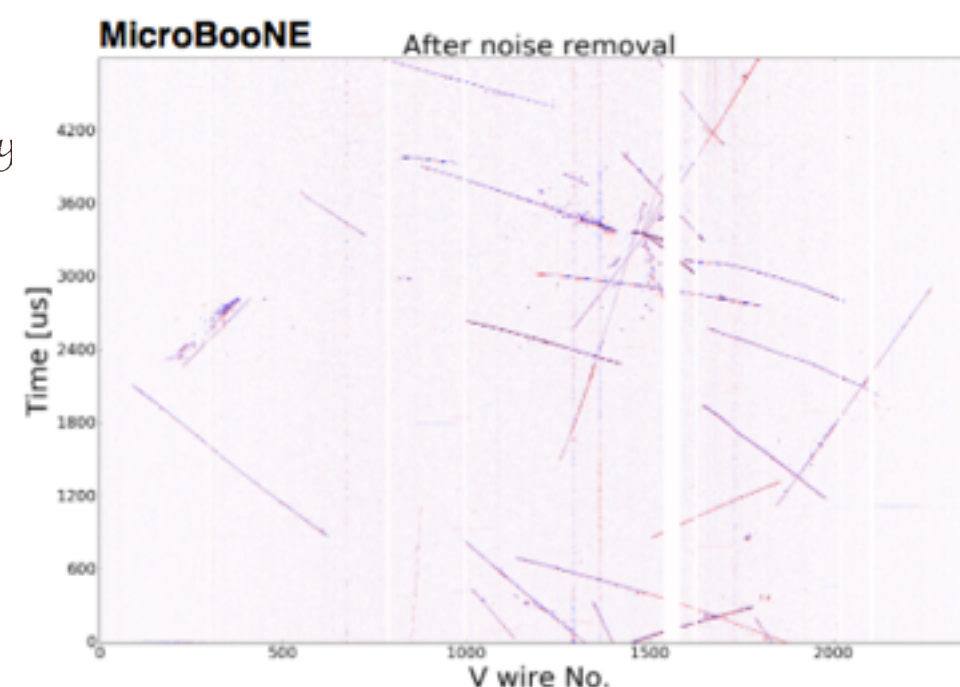
- Pandora provides a multi-algorithm approach to automated pattern recognition for LArTPC detectors such as MicroBooNE

- Addresses problem with $\mathcal{O}(100)$ algorithms to build the event (each algorithm addresses a specific task in a particular topology)

- PandoraSDK provides the software infrastructure to manage the algorithm chain. Eur. Phys. J. C 75, no. 9, 439
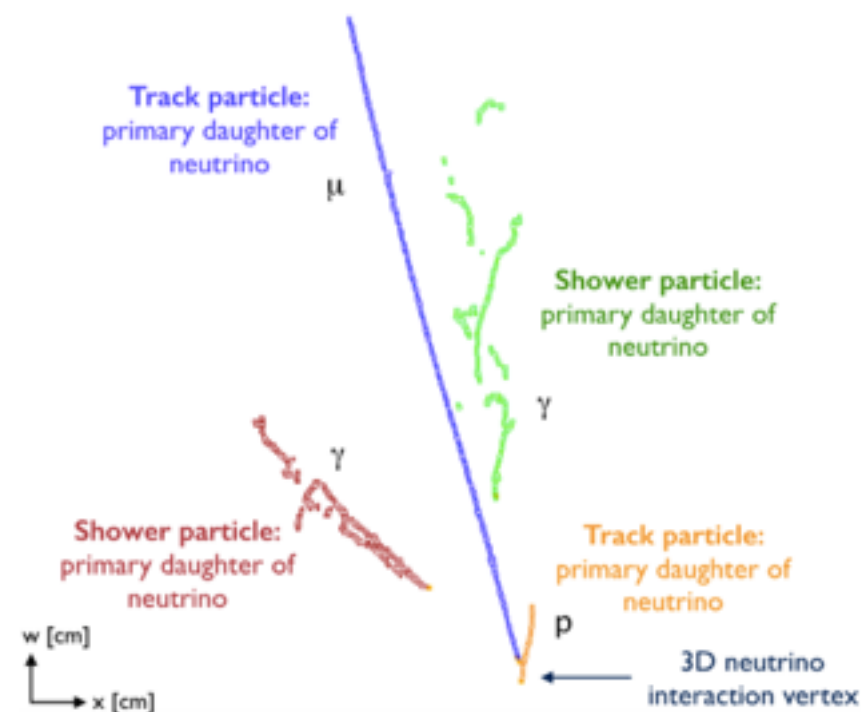
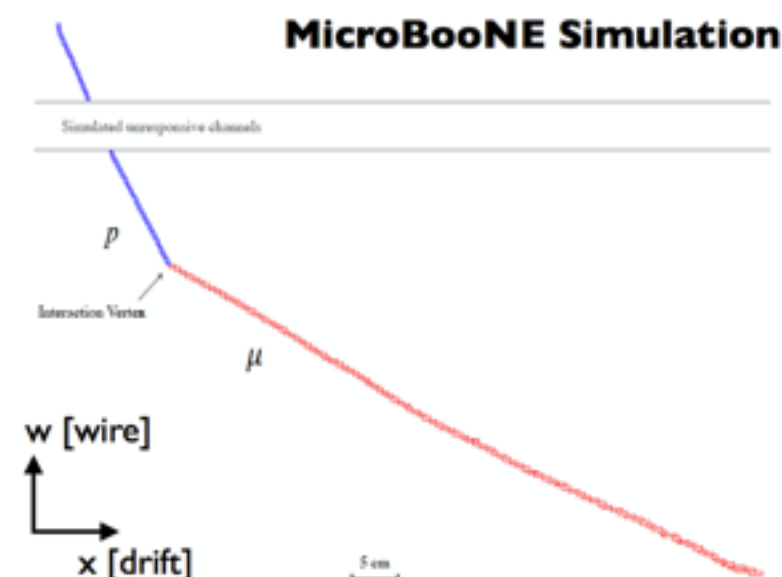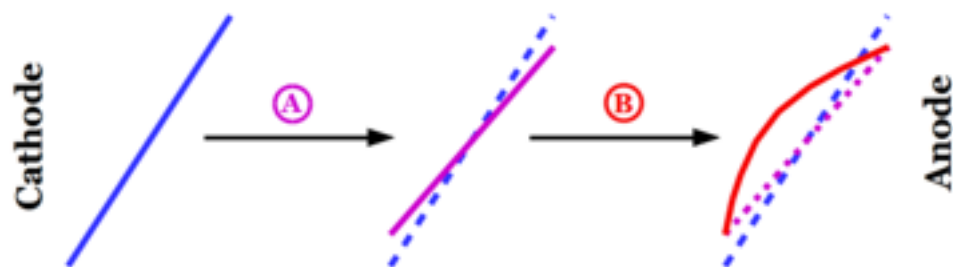MicroBooNE Public Note 1015

Matching of true-reconstructed particles

$$CCQEL\ \nu_\mu \rightarrow \mu + p$$

#Matched Particles	0	1	2	3+
μ	1.3%	95.8%	2.9%	0.1%
p	8.9%	87.3%	3.6%	0.2%

arxiv:1708.03135, submitted to EPJC

MicroBooNE Simulation

- Accumulated positive LAr ions creates a Space Charge Effect (SCE) in the TPC, distorting reconstructed tracks

- A small muon tagger (MuCS) installed above the TPC was used to study the SCE with reconstructed entry and exit points for muons …
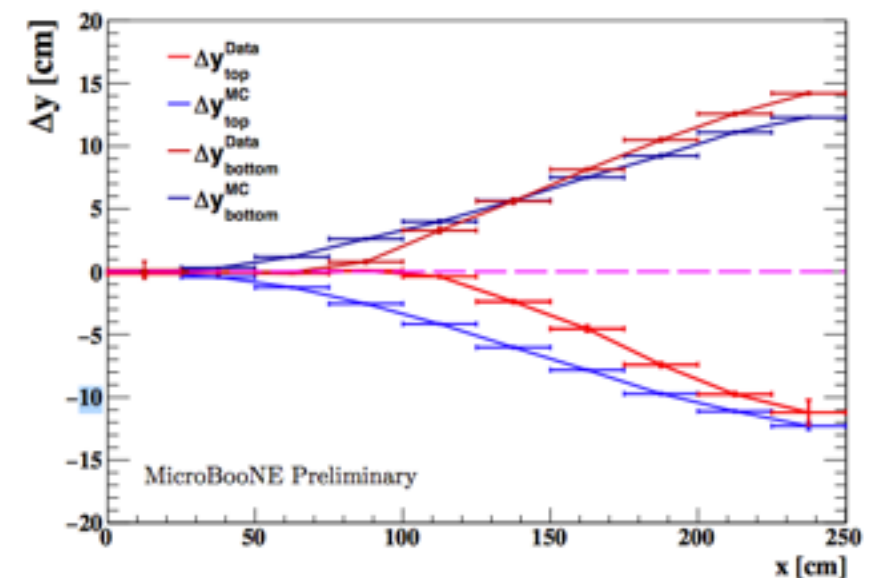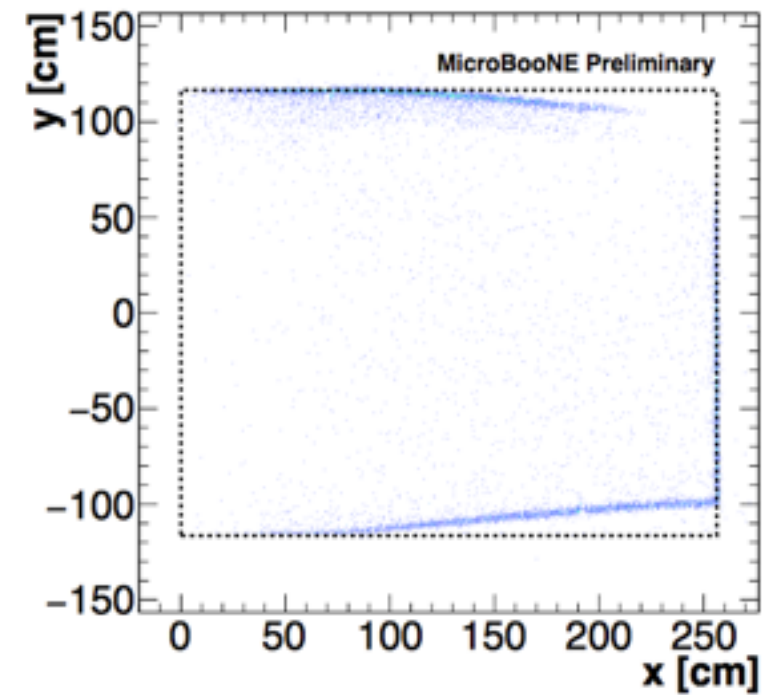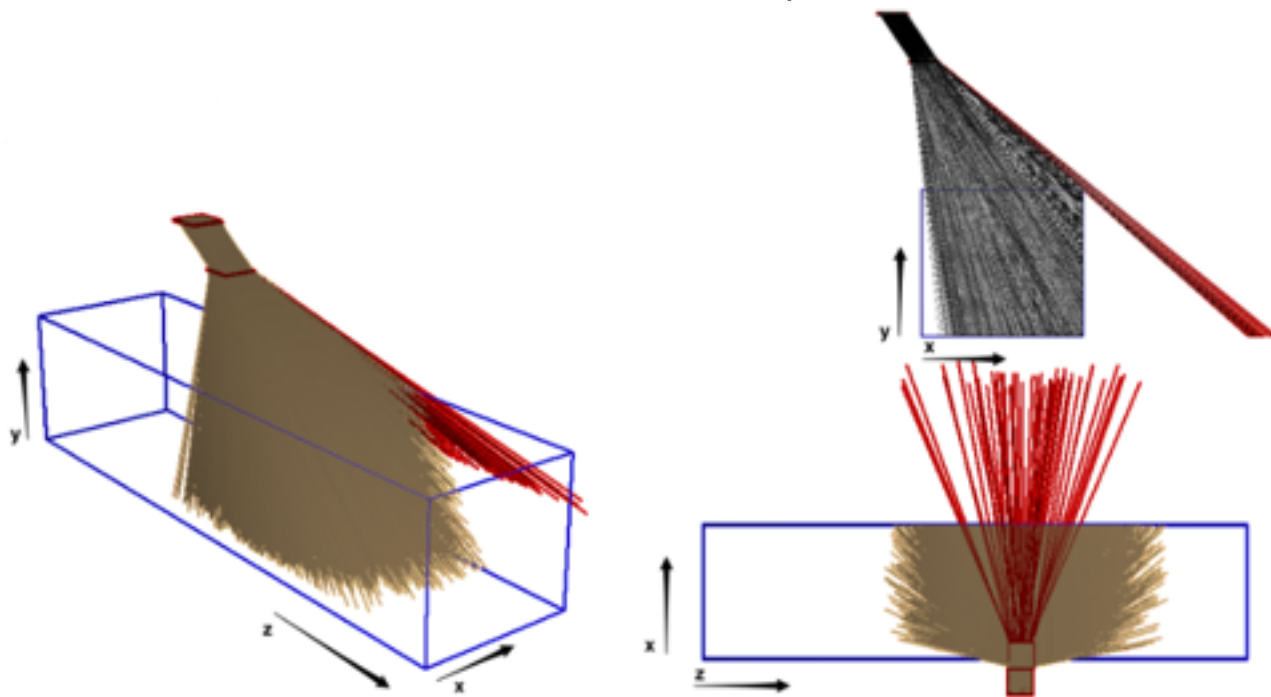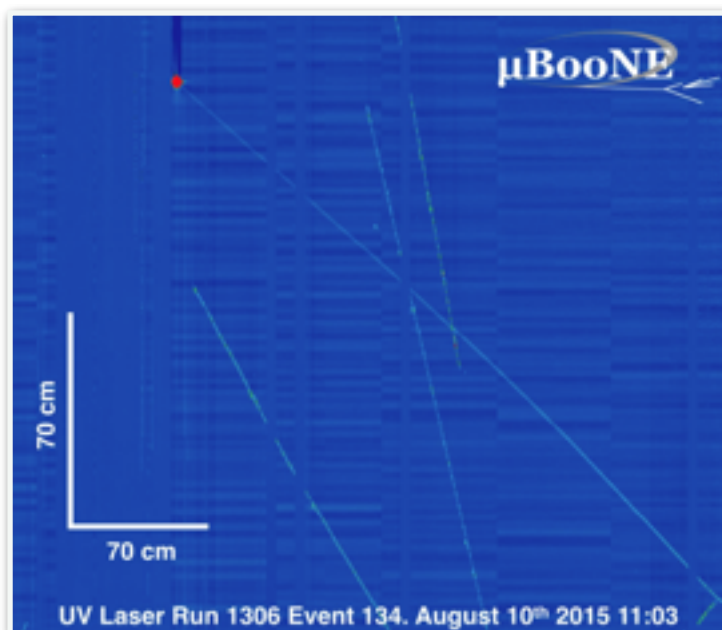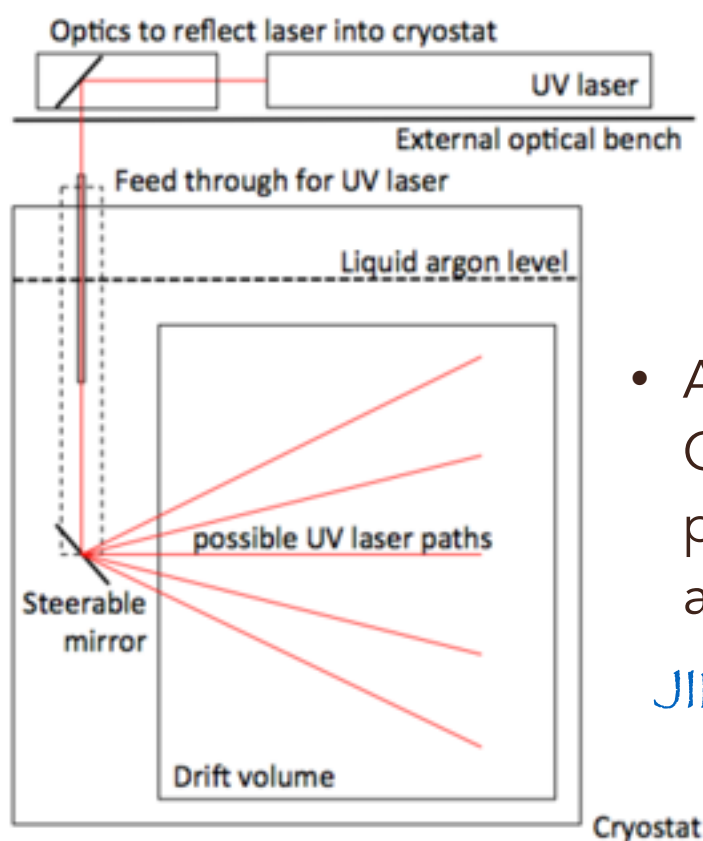

… and determine the necessary corrections to the SCE

MicroBooNE Public Note 1018

Optics to reflect laser into cryostat
UV laser
External optical bench
Feed through for UV laser
Liquid argon level
possible UV laser paths
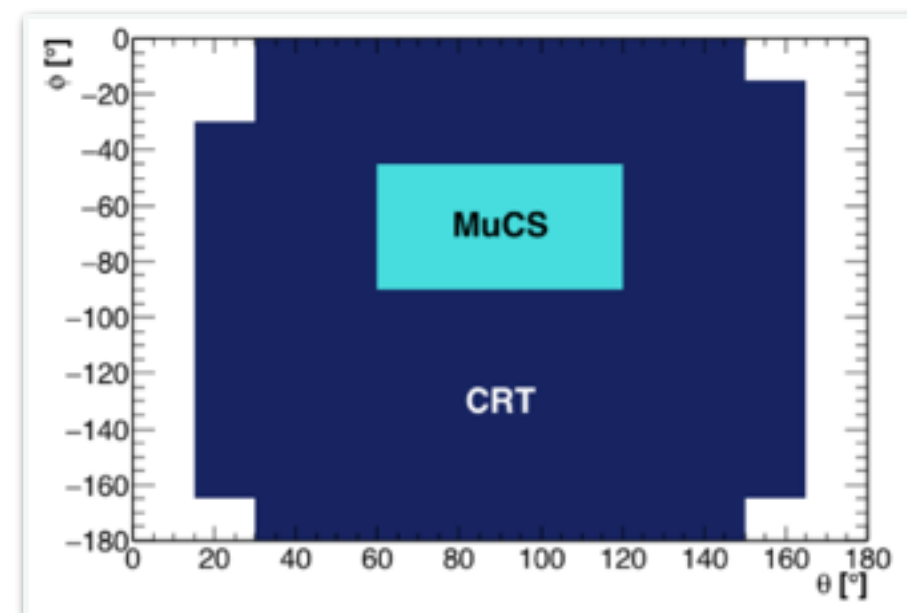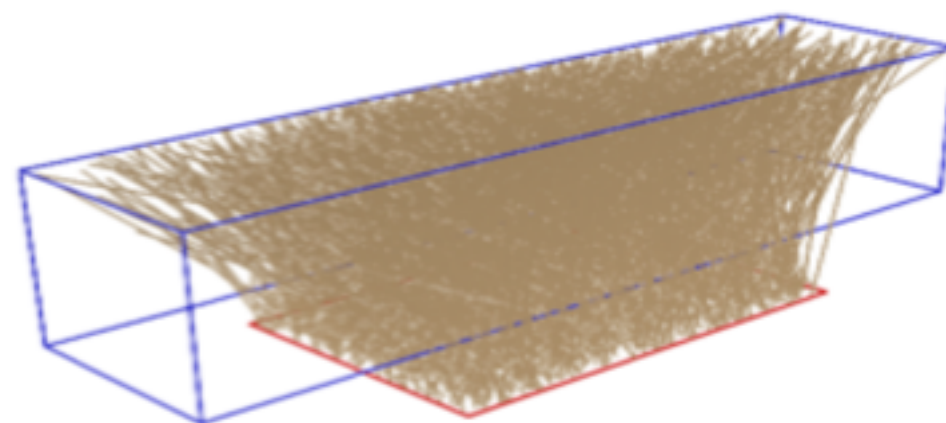Steerable mirror
Drift volume
Cryostat

Similar studies can be performed
(& improved) by using:

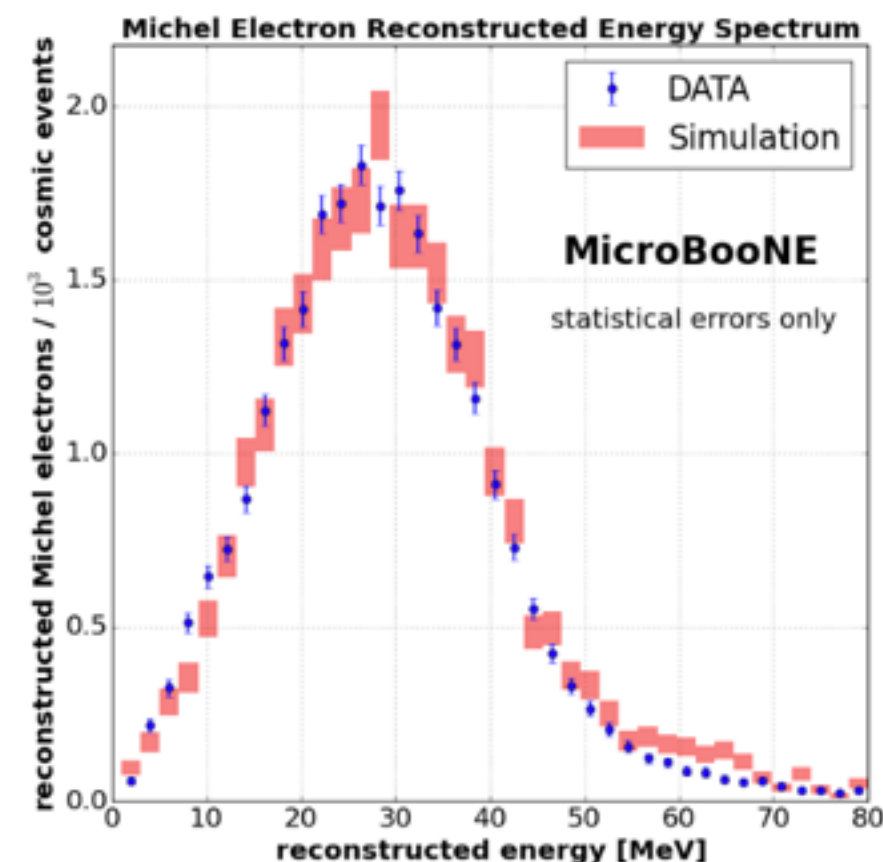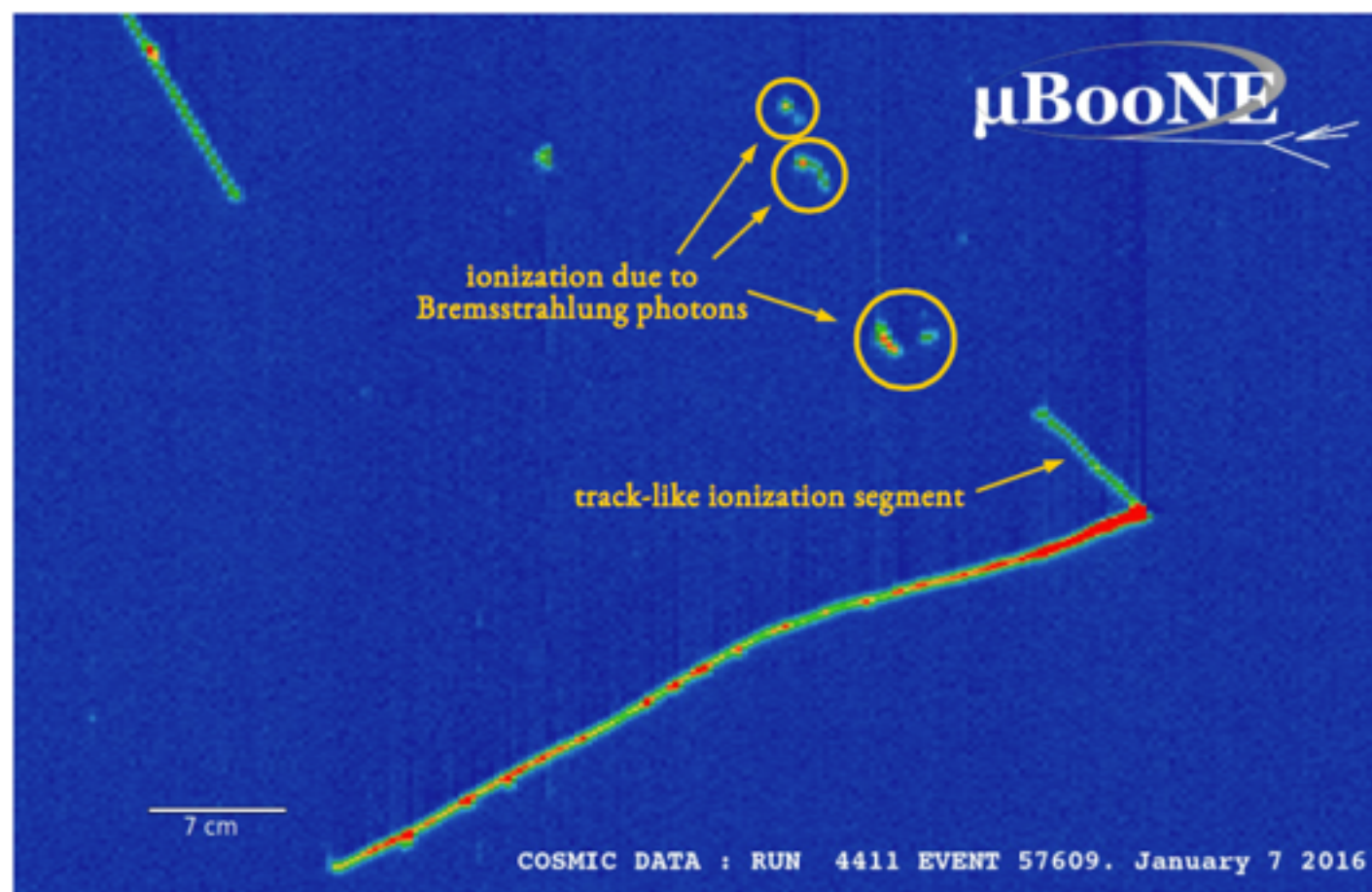- A steerable UV Laser Calibration source producing straight tracks across the TPC

  JINST 9, T11007 (2014)

- Cosmic Ray Tagger system providing larger coverage for crossing muons

UV Laser Run 1306 Event 134. August 10th 2015 11:03

MuCs - CRT coverage comparison

COSMIC DATA : RUN 4411 EVENT 57609. January 7 2016

- Michel electrons produced by decay at rest of cosmic muons are used for low energy response studies.

- At these energies, up to 50 MeV, ionization electrons and bremsstrahlung contribute similarly to electron energy loss in LAr.

Fully-automated set of algorithms for reconstructing these EM showers.

arxiv:1704.02927, submitted to JINST
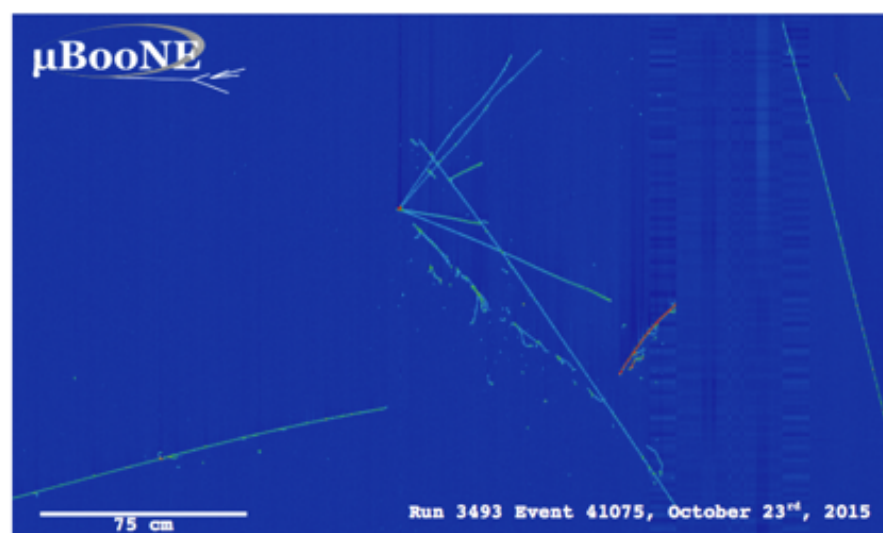
MicroBooNE
Simulation + Data Overlay
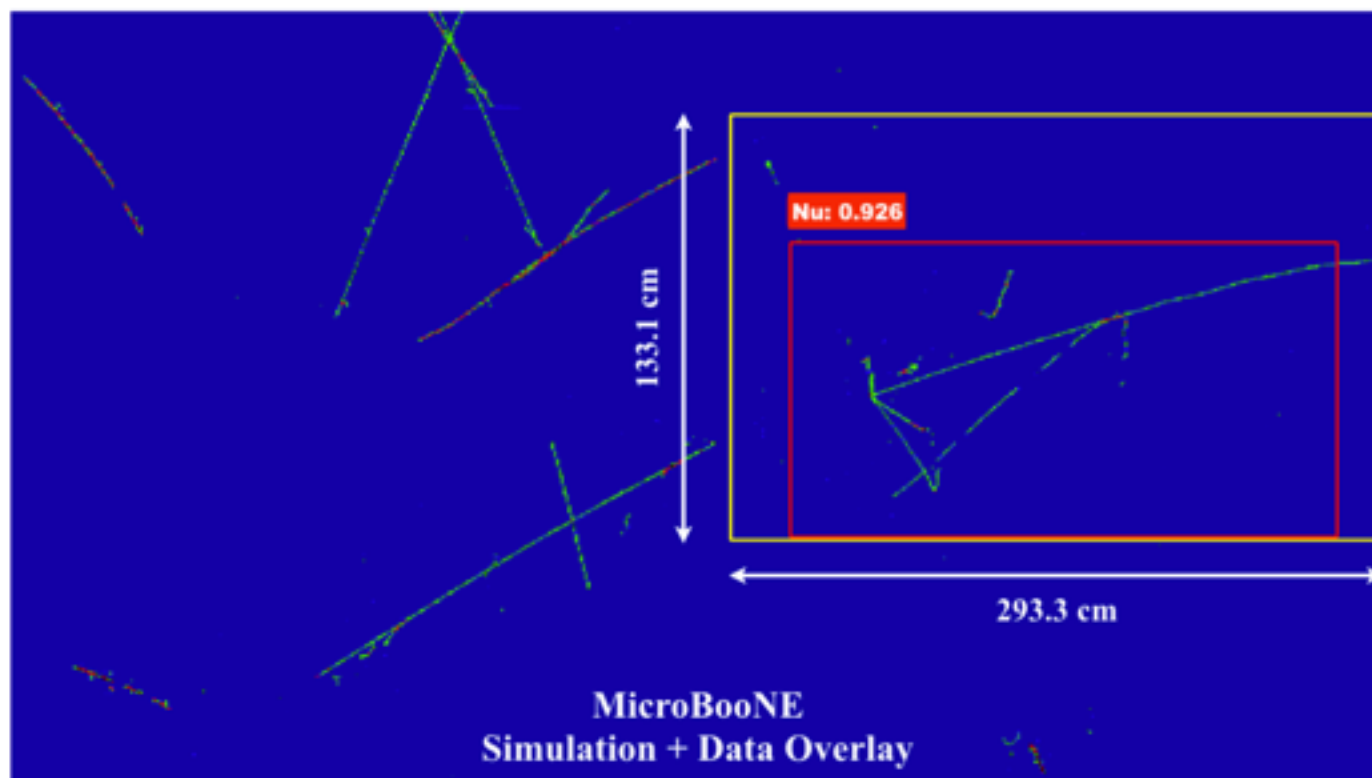
- Machine Learning (Neural Networks for image recognition) used for analysis of high quality images provided by MicroBooNE

  JINST 12, P03011 (2017)

- Studies with MC data demonstrate the potential of these tools for particle ID and finding neutrino events and vertex interactions.
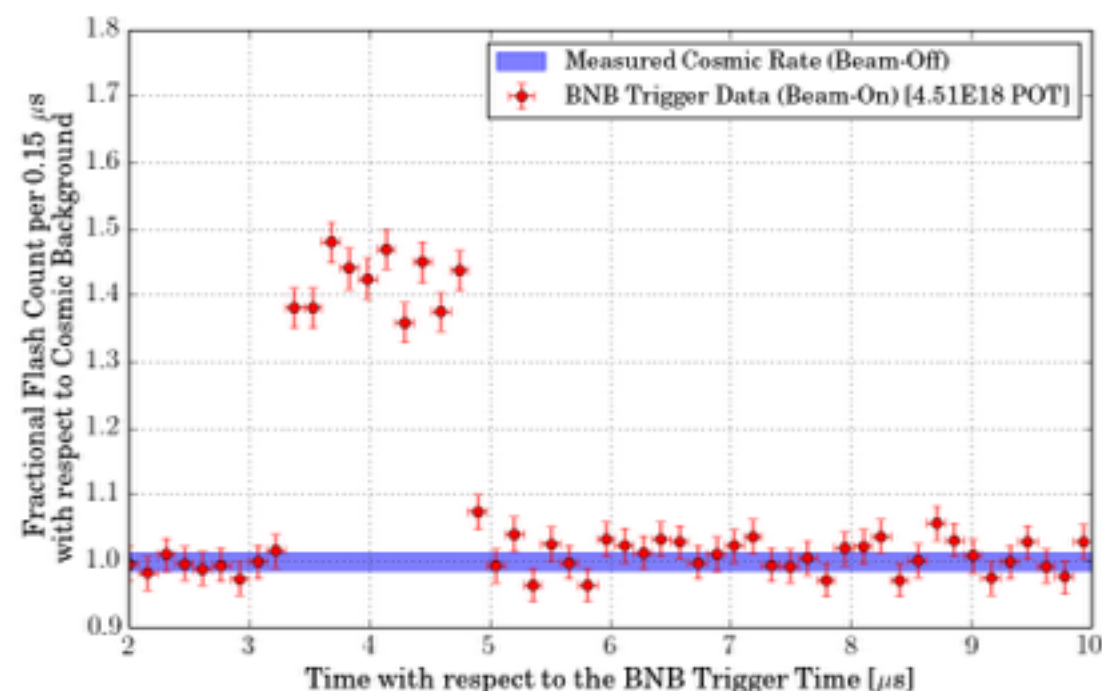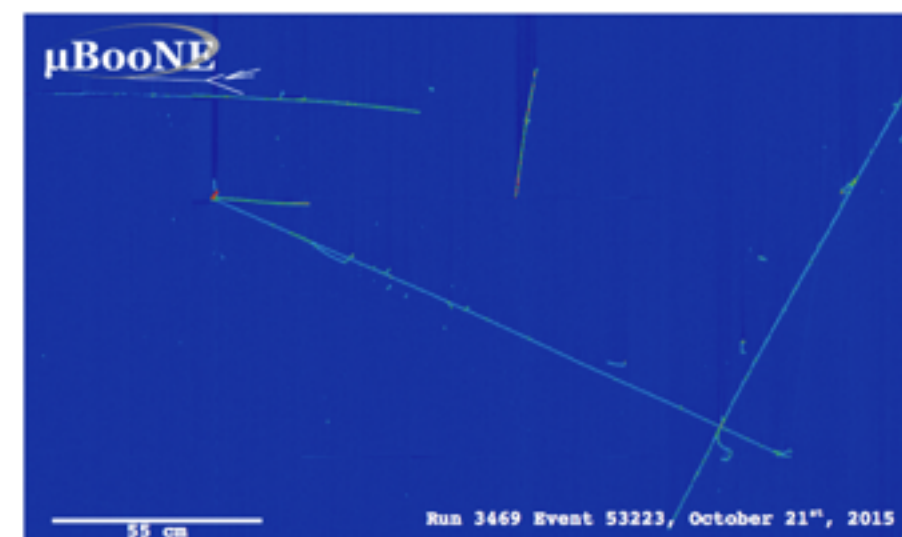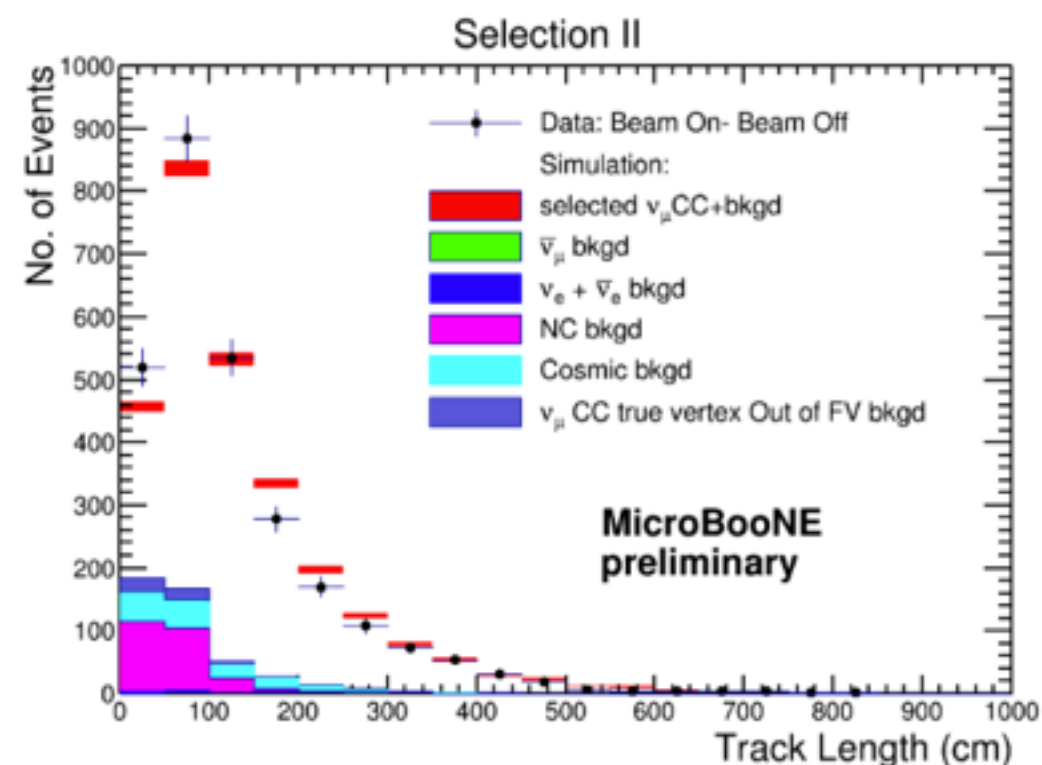
Application to BNB data soon
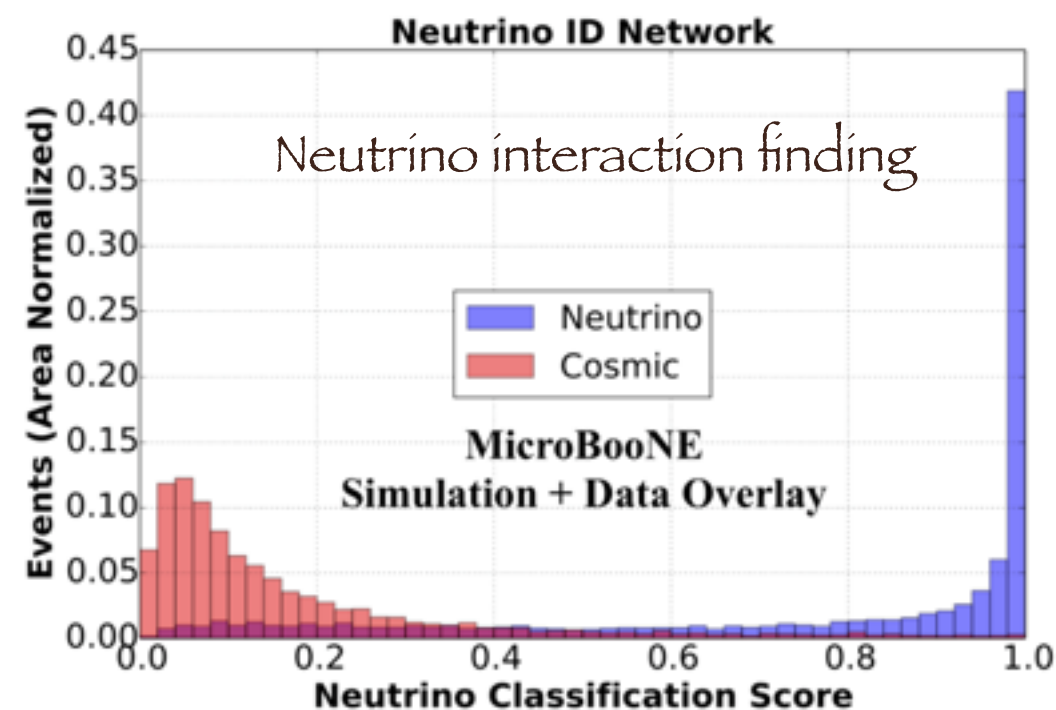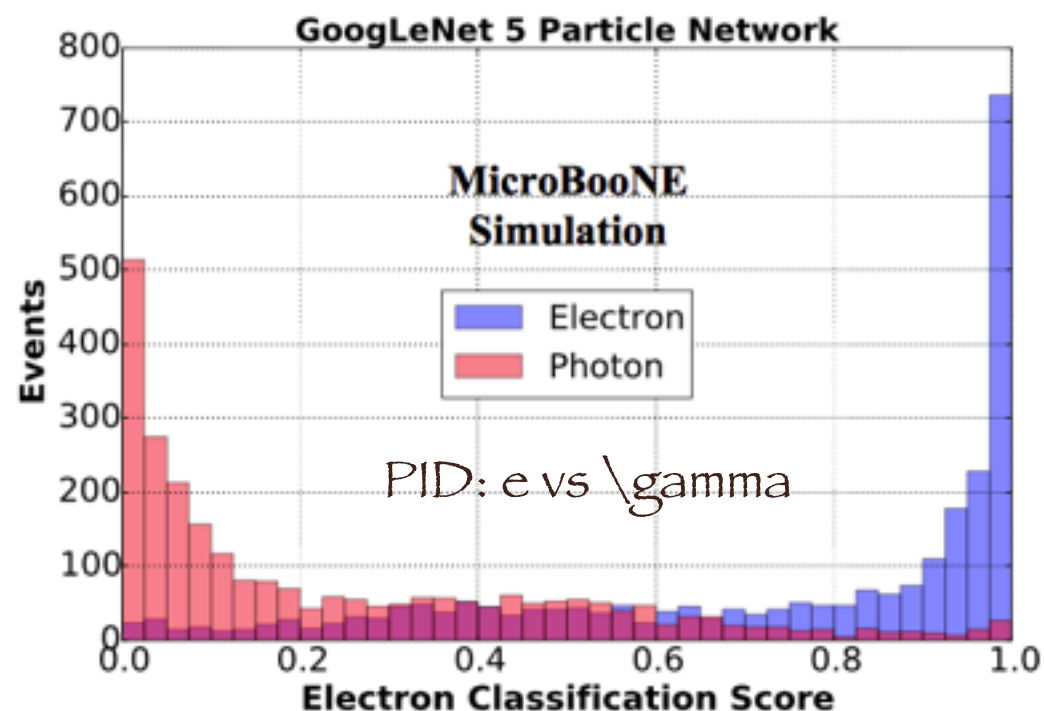
Successful automated reconstruction and neutrino event selection using LArSoft

MicroBooNE Public Note 1010

Optical reconstruction in coincidence with beam spills

First kinematic event distributions

- **MicroBooNE** is the **first operating detector** of the SBN program, collecting and analysing data since October 2015.

- More than **6.0e20 BNB** (8.5e20 NuMI) POT have been collected.

- Algorithms for **automatic reconstruction** are functioning.

- Continuous **upgrades** to **hardware and software** further improve detector performance.

- Installation of an external **Cosmic Ray Tagger** System for mitigating surface operation effects.

- Several **analyses and publications** already out and more to follow (Noise Characterisation, Michel electrons, Neural Networks, etc.).

Thank you!!!
Cám ơn!!!